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Patterson

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(54) **SEEDING REPLICATION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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Related U.S. Application Data

(63) Continuation of application No. 12/890,688, filed on Sep. 26, 2010, now Pat. No. 8,527,455, which is a continuation of application No. 11/807,204, filed on May 24, 2007, now Pat. No. 7,827,137.

(60) Provisional application No. 60/925,624, filed on Apr. 19, 2007.

(51) **Int. Cl.**
G06F 17/30 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 17/30174*** (2013.01); ***G06F 17/30159*** (2013.01); ***G06F 17/30212*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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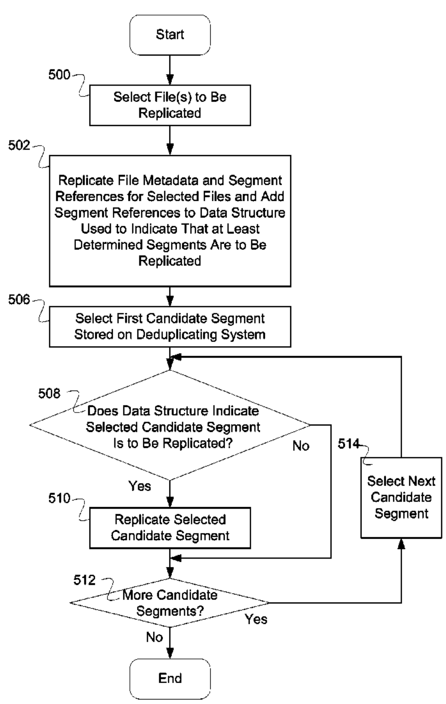
(57) **ABSTRACT**

A system, method and computer program product for determining one or more candidate segments for replication. One or more but not all files stored on a deduplicated storage system are selected to be replicated. One or more segments referred to by the selected one or more but not all files are determined. A data structure is created that is used to indicate that at least the one or more segments are to be replicated. In the event that an indication based at least in part on the data structure indicates that a candidate segment stored on the deduplicating storage system is to be replicated, the candidate segment is replicated.

12 Claims, 12 Drawing Sheets



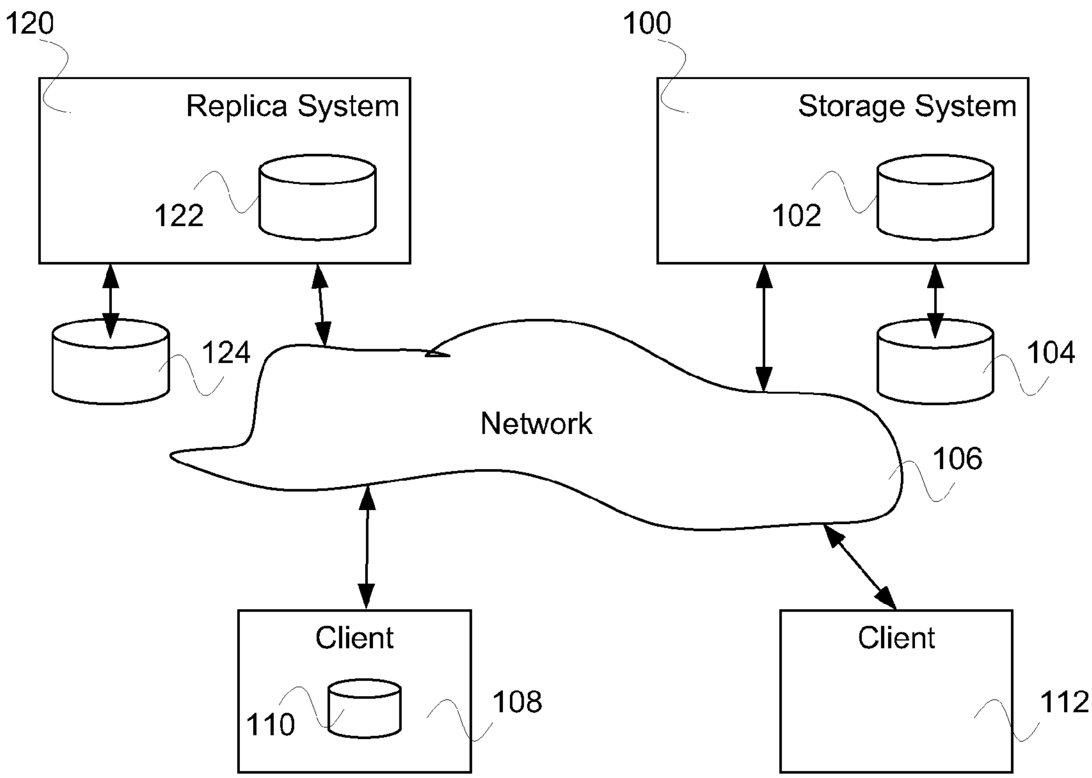

120
Replica System
122
124
100
Storage System
102
104
Network
106
Client
110
108
Client
112

FIG. 1

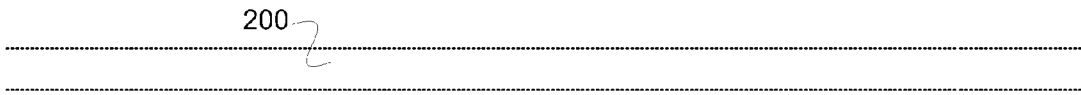


FIG. 2A

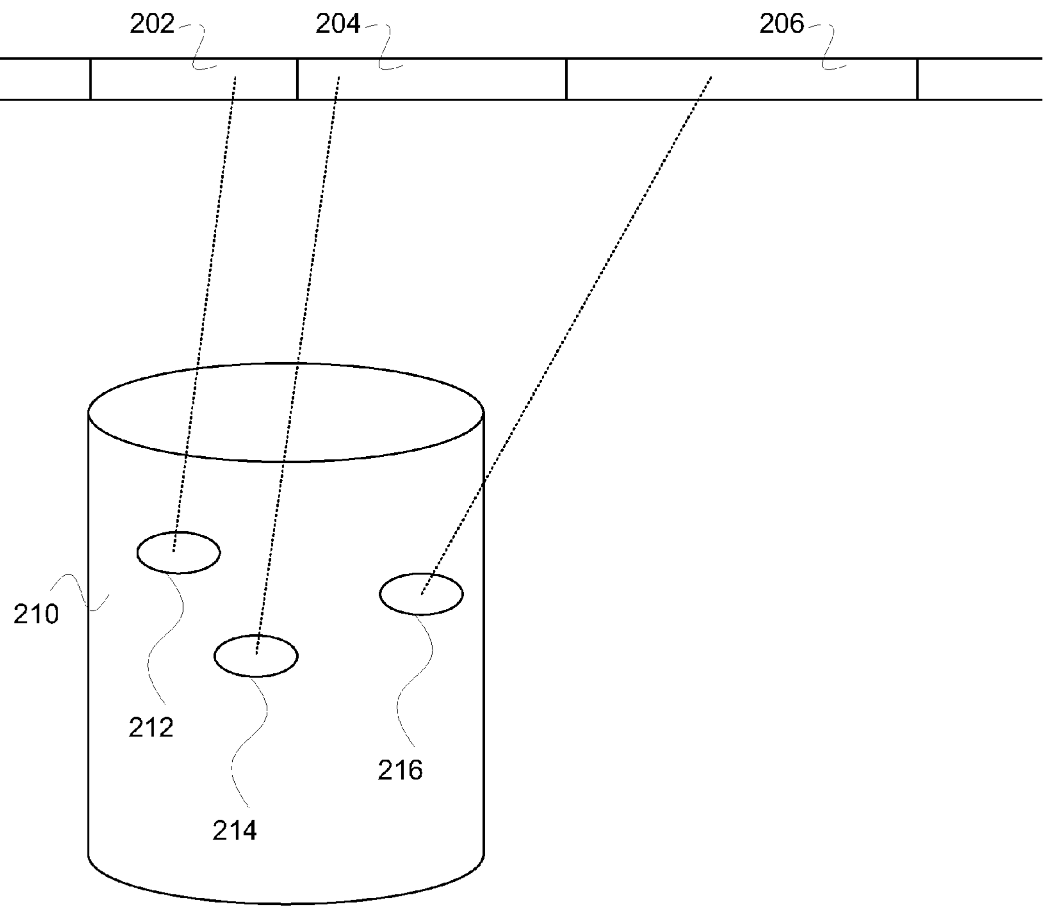


FIG. 2B

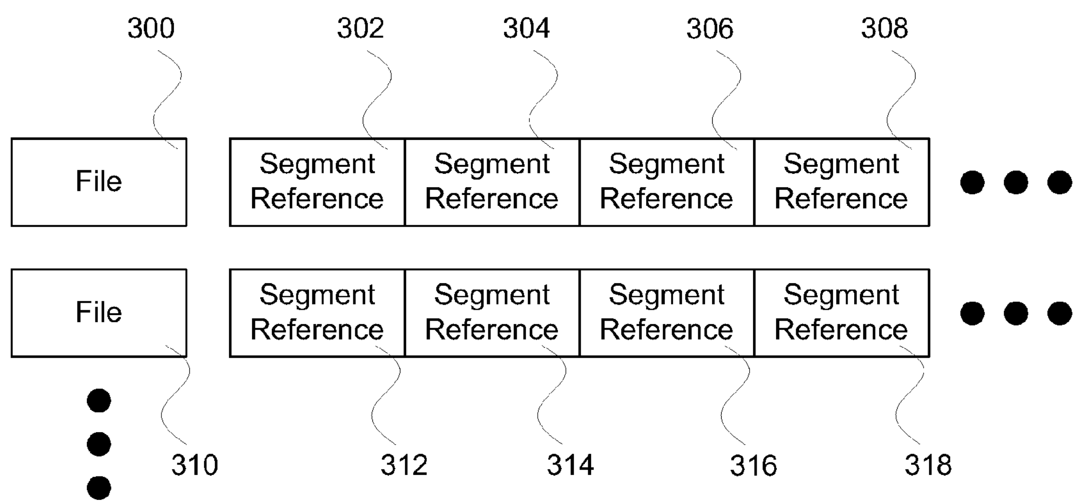

300
302
304
306
308
File
Segment Reference
Segment Reference
Segment Reference
Segment Reference
File
Segment Reference
Segment Reference
Segment Reference
Segment Reference
310
312
314
316
318

FIG. 3

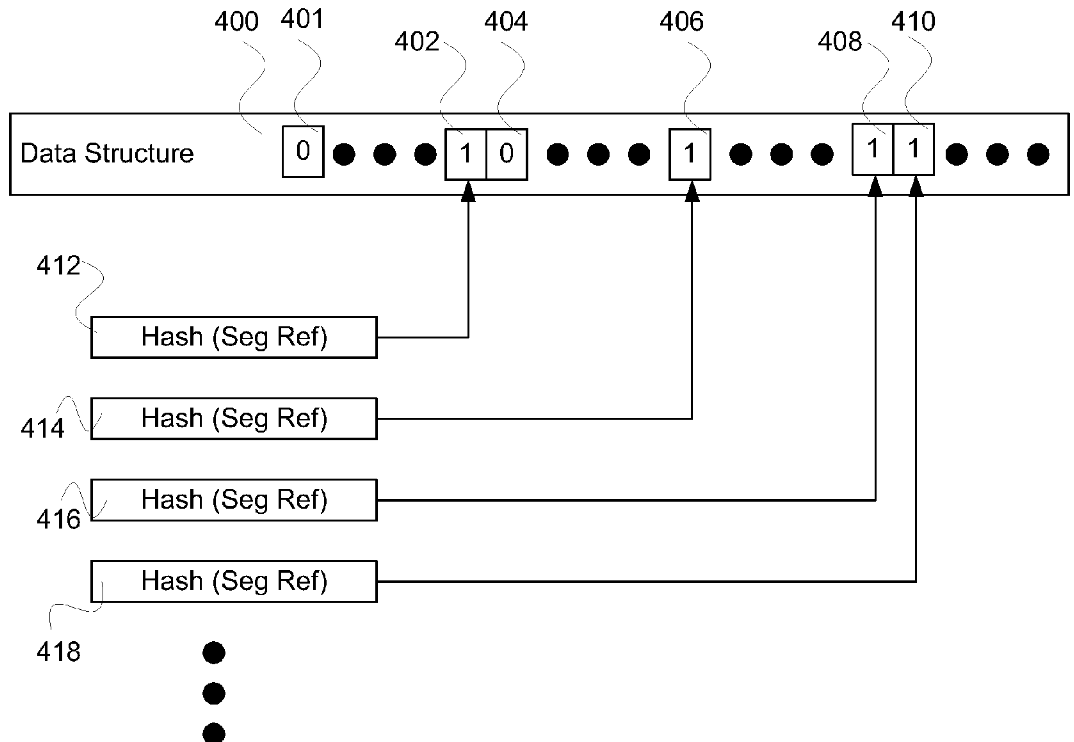

400
401
402
404
406
408
410
Data Structure
0
1
0
1
1
1
412
Hash (Seg Ref)
414
Hash (Seg Ref)
416
Hash (Seg Ref)
Hash (Seg Ref)
418

FIG. 4A

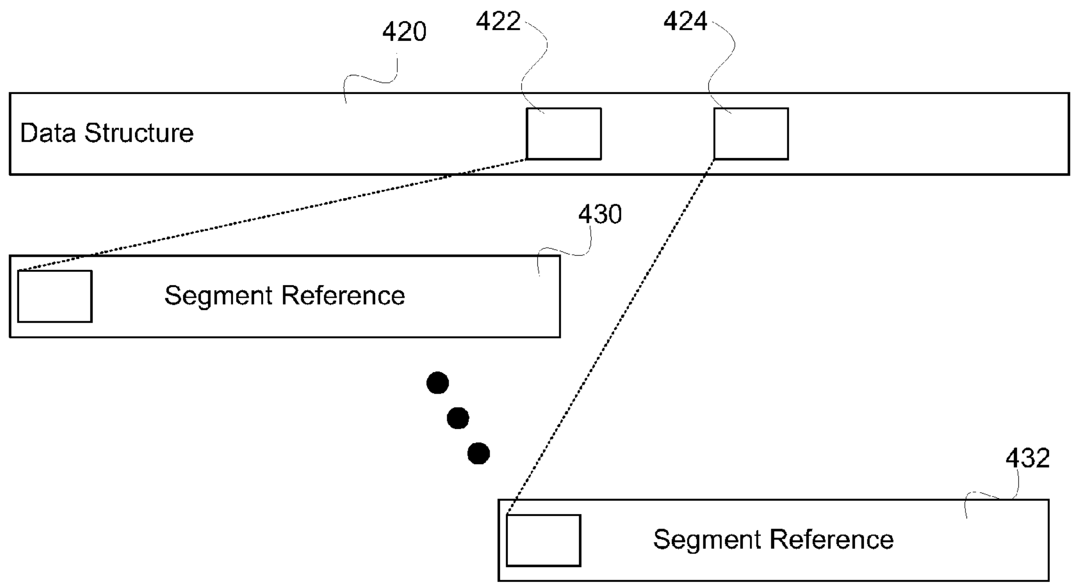

420
422
424
Data Structure
430
Segment Reference
432
Segment Reference

FIG. 4B

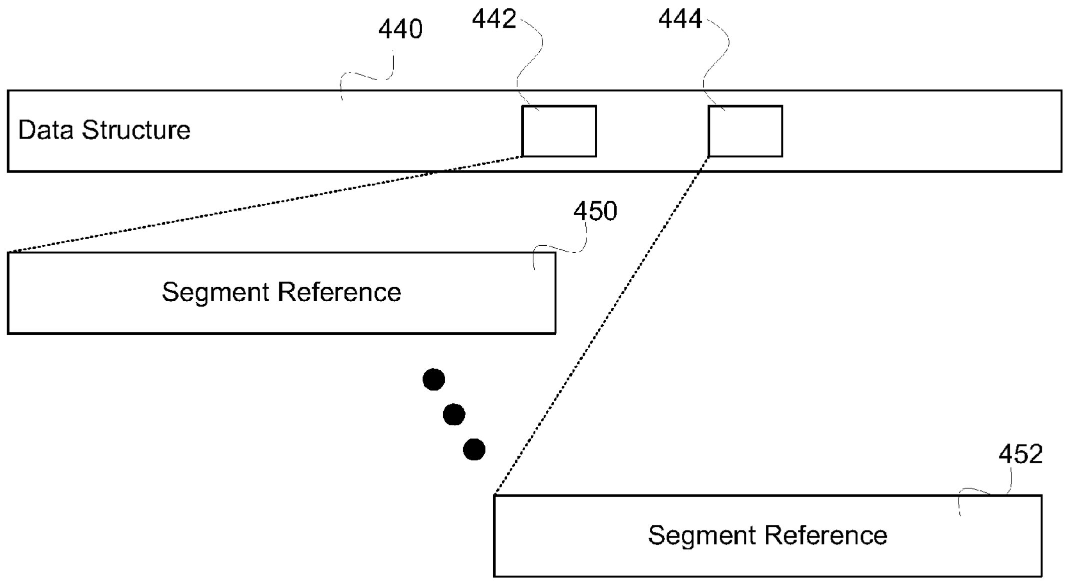

440
442
444
Data Structure
450
Segment Reference
452
Segment Reference

FIG. 4C

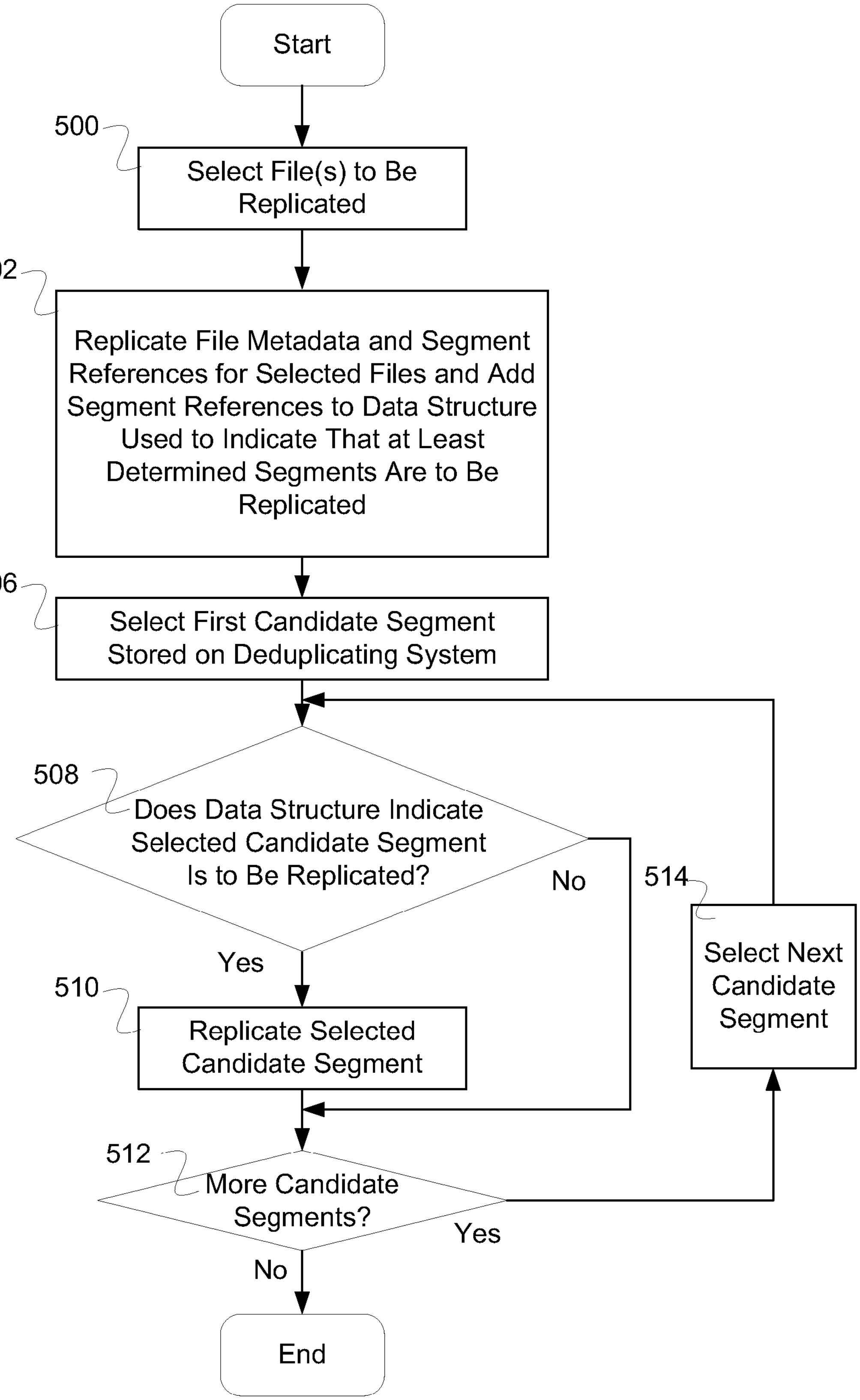

Start
500
Select File(s) to Be Replicated
502
Replicate File Metadata and Segment References for Selected Files and Add Segment References to Data Structure Used to Indicate That at Least Determined Segments Are to Be Replicated
506
Select First Candidate Segment Stored on Deduplicating System
508
Does Data Structure Indicate Selected Candidate Segment Is to Be Replicated?
No
Yes
510
Replicate Selected Candidate Segment
514
Select Next Candidate Segment
512
More Candidate Segments?
Yes
No
End

FIG. 5

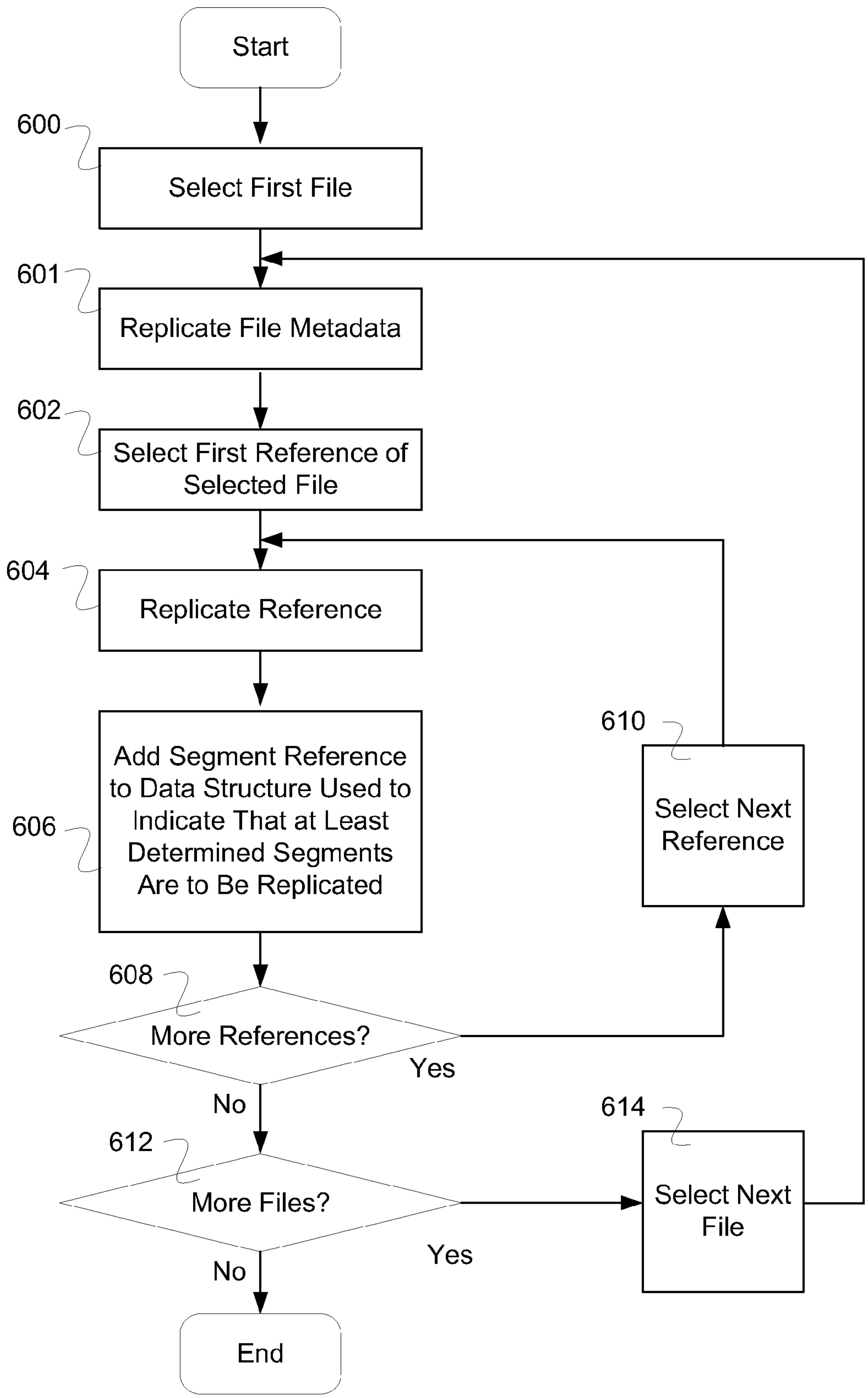

Start
600
Select First File
601
Replicate File Metadata
602
Select First Reference of Selected File
604
Replicate Reference
606
Add Segment Reference to Data Structure Used to Indicate That at Least Determined Segments Are to Be Replicated
608
More References?
Yes
No
610
Select Next Reference
612
More Files?
Yes
No
614
Select Next File
End

FIG. 6

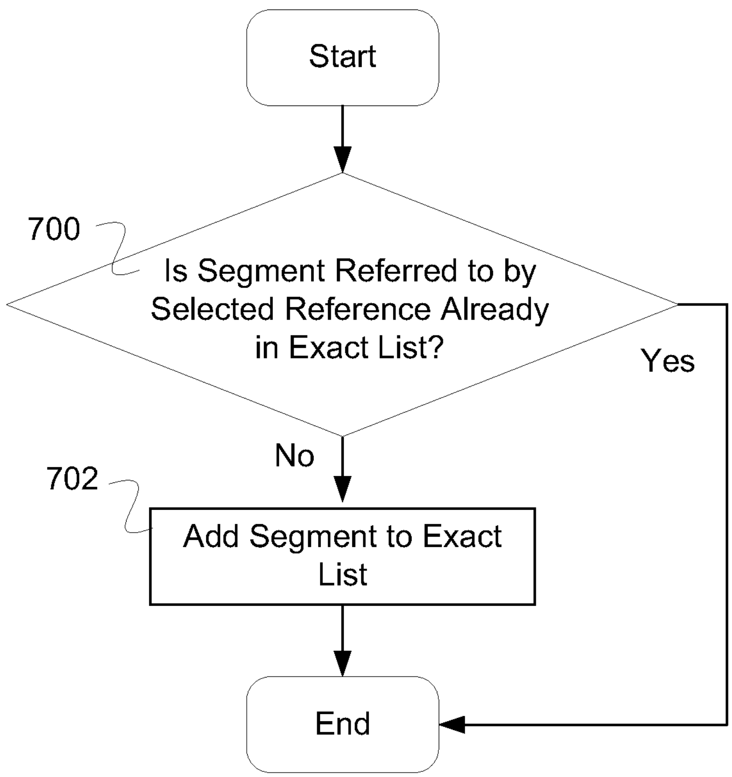

Start
700
Is Segment Referred to by Selected Reference Already in Exact List?
Yes
No
702
Add Segment to Exact List
End

FIG. 7A

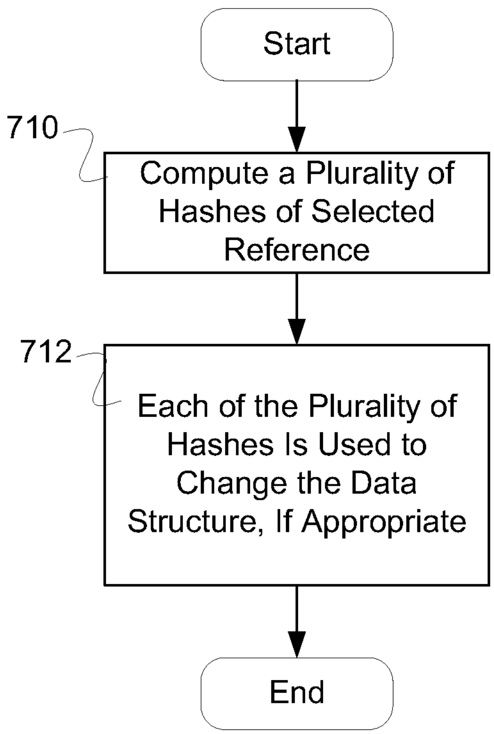

Start
710
Compute a Plurality of Hashes of Selected Reference
712
Each of the Plurality of Hashes Is Used to Change the Data Structure, If Appropriate
End

FIG. 7B

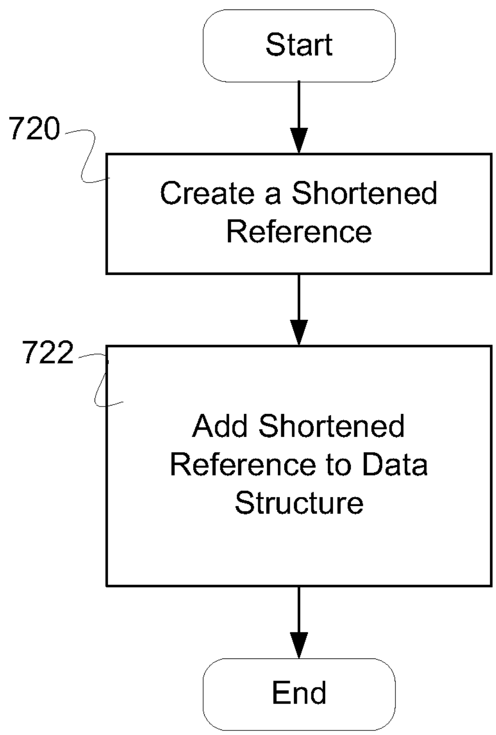

Start
720
Create a Shortened Reference
722
Add Shortened Reference to Data Structure
End

FIG. 7C

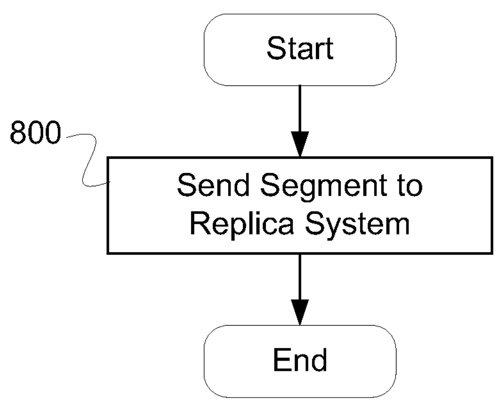


FIG. 8A

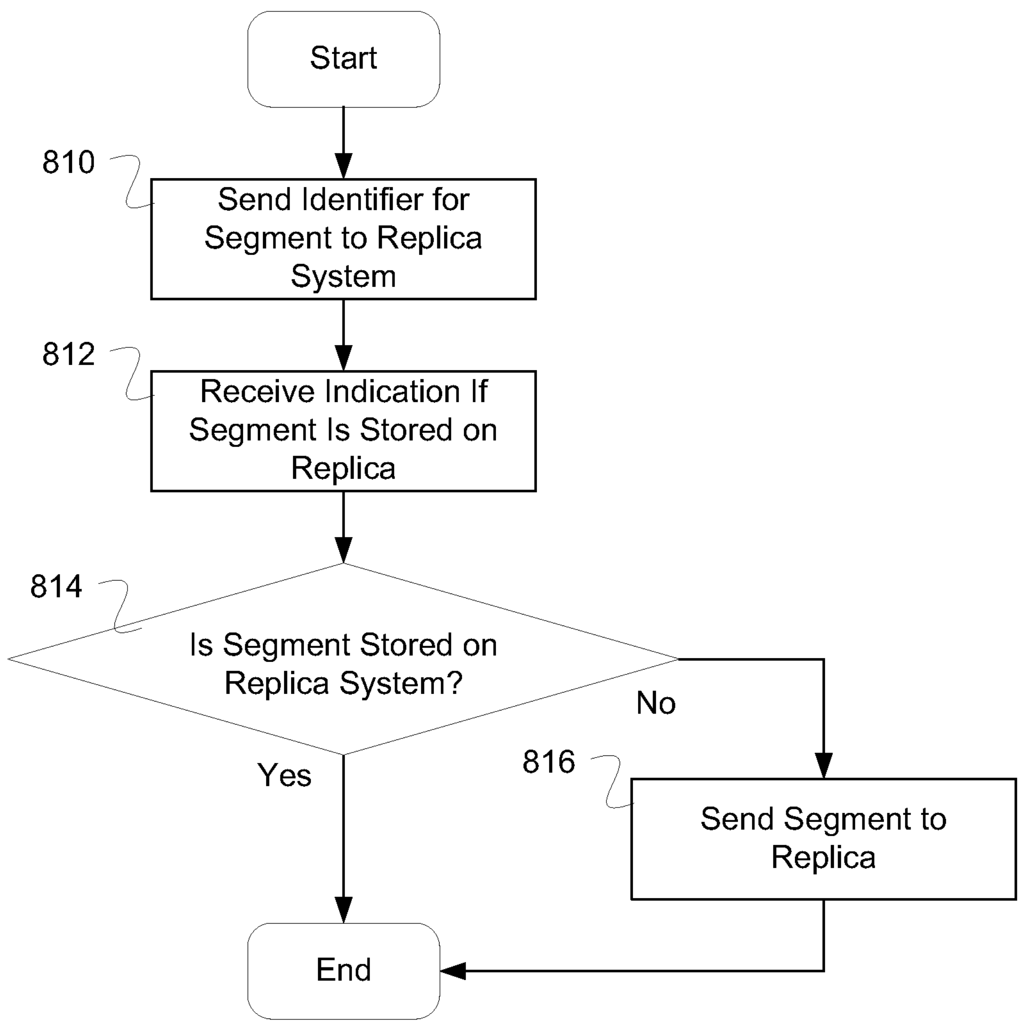

Start
810
Send Identifier for Segment to Replica System
812
Receive Indication If Segment Is Stored on Replica
814
Is Segment Stored on Replica System?
No
Yes
816
Send Segment to Replica
End

FIG. 8B

SEEDING REPLICATION

This application is a continuation of U.S. patent application Ser. No. 12/890,688, now U.S. Pat. No. 8,527,455, entitled SEEDING REPLICATION filed Sep. 26, 2010, which is incorporated herein by reference for all purposes, which is a continuation of U.S. patent application Ser. No. 11/807,204, now U.S. Patent No. 7,827,137, entitled SEEDING REPLICATION filed May 24, 2007, which is incorporated herein by reference for all purposes, which claims priority to U.S. Provisional Patent Application No. 60/925,624 entitled SEEDING REPLICATION filed Apr. 19, 2007, which is incorporated herein by reference for all purposes.

BACKGROUND OF THE INVENTION

A replica system stores the same data or a portion of the same data as an originating system. The replica system can be used to recover data when data in the originating system is corrupted or lost. For efficiency of storage, both the replica and the originating system may be deduplicating systems in which in-coming data is broken up into segments, and if the segment is already stored on the system, a reference to the already-stored segment is stored instead of storing the segment again. Deduplication typically results in a substantial (e.g., 10×) reduction in the amount of space required to store data for the system.

When first starting replication from one system to another, if the replica is to store all of the same data as the originating system, then the task is clear: transfer all the data over. This is efficient for a deduplicating system, since only the deduplicated segments and the references that enable file reconstruction need to be sent. However, if the replica is to store only a portion of the data on the originator system, then it is not obvious which of the segments stored need to be sent over to the replica. One simple solution is to run through the list of references to segments for the portion of the data to be stored on the replica and ask the replica system if the referred to segment has already been stored. The segment is then only transmitted in the event that it is not already on the replica system. However, this requires back and forth traffic for each reference in the list and checking by the replica system for each reference of a segment. With deduplication, there may be many times more of such references than there are actual data segments. It would be beneficial to be able seed replication for a portion of data stored on a deduplicated system without generating traffic and checking for each reference of a segment.

An analogous situation exists when copying a portion of the data stored on one deduplicated system to a second deduplicated system on a one-time basis. All of the segments referenced by the portion of the data being copied need to be sent to the second system. However, as above, checking each reference to see if the corresponding segment is to be sent to a second system, can create substantial traffic between the two systems for each reference that needs to be checked. It would be beneficial to be able to copy a portion of data stored on a deduplicated system without generating traffic and checking for each reference of a segment.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments of the invention are disclosed in the following detailed description and the accompanying drawings.

FIG. **1** is a block diagram illustrating an embodiment of a system for seeding replication.

FIG. **2**A is a block diagram illustrating an embodiment of a portion of a data stream or data block.

FIG. **2**B is a block diagram illustrating an embodiment of segmenting a portion of a data stream or a data block.

FIG. **3** is a block diagram illustrating an embodiment of file references.

FIG. **4**A is a block diagram illustrating an embodiment of a data structure.

FIG. **4**B is a block diagram illustrating an embodiment of a data structure.

FIG. **4**C is a block diagram illustrating an embodiment of a data structure.

FIG. **5** is a flow diagram illustrating an embodiment of a process for seeding replication.

FIG. **6** is a flow diagram illustrating an embodiment of a process for determining referenced segments.

FIG. **7**A is a flow diagram illustrating an embodiment of a process for adding to a data structure.

FIG. **7**B is a flow diagram illustrating an embodiment of a process for adding to a data structure.

FIG. **7**C is a flow diagram illustrating an embodiment of a process for adding to a data structure.

FIG. **8**A is a flow diagram illustrating an embodiment of a process for replicating a segment.

FIG. **8**B is a flow diagram illustrating an embodiment of a process for replicating a segment.

DETAILED DESCRIPTION

The invention can be implemented in numerous ways, including as a process, an apparatus, a system, a composition of matter, a computer readable medium such as a computer readable storage medium or a computer network wherein program instructions are sent over optical or communication links. In this specification, these implementations, or any other form that the invention may take, may be referred to as techniques. A component such as a processor or a memory described as being configured to perform a task includes both a general component that is temporarily configured to perform the task at a given time or a specific component that is manufactured to perform the task. In general, the order of the steps of disclosed processes may be altered within the scope of the invention.

A detailed description of one or more embodiments of the invention is provided below along with accompanying figures that illustrate the principles of the invention. The invention is described in connection with such embodiments, but the invention is not limited to any embodiment. The scope of the invention is limited only by the claims and the invention encompasses numerous alternatives, modifications and equivalents. Numerous specific details are set forth in the following description in order to provide a thorough understanding of the invention. These details are provided for the purpose of example and the invention may be practiced according to the claims without some or all of these specific details. For the purpose of clarity, technical material that is known in the technical fields related to the invention has not been described in detail so that the invention is not unnecessarily obscured.

Seeding replication is disclosed. In a deduplicated system, seeding replication for a portion of the data sharing a common pool of segments on an originating system requires determining the segments referenced that enable the reconstruction of the portion of data. A list or a data structure can be generated that contains information regarding referenced segments. For unique segments stored on the originator system, each can be checked using the list or data structure to see if the segment has been referenced by the portion of data. If the segment has been referenced, the segment is sent to the replica system. This allows the communications back and forth between the originating system and the replica system to be reduced to the segment level instead of the reference level. Also, in the case of the data structure, efficient use of memory is possible, since the vector is substantially smaller than the list of unique referenced segments. In addition, the list or the data structure is generated on the originator system without any communication with the replica system saving communication bandwidth between the originator and replica systems.

In some embodiments, multiple files will refer to the same stored segment because the content of a segment in the different files is the same. This is in contrast to a situation where multiple versions of the same file are stored on the same system (e.g., when multiple snapshots of a system are stored on one system) where each of the multiple versions of the same file refer to the same segment. A file may implement a file in a file system, a logical block device, a virtual tape cartridge, a database table, or any other kind of data object or a portion of such a data object that a data storage system may store.

FIG. **1** is a block diagram illustrating an embodiment of a system for seeding replication. In the example shown, storage system **100** stores data for clients represented in FIG. **1** by client **112** and client **108**. A client may have a local storage device in addition to local memory. For example, client **108** has storage **110** whereas client **112** does not have a local storage device. Storage system **100** stores data either using internal storage device **102** or attached external storage device **104**.

Storage system **100** communicates with clients via network **106**. Network **106** comprises one or more of the following: a local area network, a wide area network, a wired network, a wireless network, the Internet, a fiber network, or any other appropriate network enabling communication. Storage system **100** communicates with replica system **120** via network **106** as well. Replica system **120** includes internal storage device **122** and is connected to external storage device **124**.

Replica system **120** stores all or a portion of data stored on storage system **100**. Initially, all or the portion of data stored on storage system **100** is replicated on replica system **120** by sending appropriate data via network **106**. After the initial seeding, replica system **120** is updated by sending from storage system **100** new data. Updating can be continuous, sent in bursts on a regular schedule, when the amount of data exceeds a certain size, or at other appropriate times. In the case of data copying, the initial seeding completes the task and there is no subsequent updating.

In various embodiments, storage devices **102**, **104**, **122**, and **124** comprise a single storage device such as a hard disk, a tape drive, a semiconductor memory, a plurality of storage devices such as a redundant array system (e.g., a redundant array of independent disks (RAID)), a system for storage such as a library system or network attached storage system, or any other appropriate storage device or system.

FIG. **2**A is a block diagram illustrating an embodiment of a portion of a data stream or data block. In the example shown, portion of data stream or data block **200** is shown. Portion of data stream or data block **200** is received by and stored on a storage system such as storage system **100** of FIG. **1**. Portion of data stream or data block **200** is sent from one or more clients such as client **108** or **112** of FIG. **1**.

FIG. **2**B is a block diagram illustrating an embodiment of segmenting a portion of a data stream or a data block. In the example shown, the portion of the data stream or data block is segmented into a plurality of segments represented in FIG. **2**B by **202**, **204**, and **206**. The data stream or data block is segmented by creating a plurality of segments from the data stream or data block that can be used to reconstruct the data stream or data block. Segments, when used to reconstruct the data stream or data block, can be overlapping, non-overlapping, or a combination of overlapping and non-overlapping. Segment boundaries can be determined using file boundaries, directory boundaries, byte counts, content-based boundaries (e.g., when a hash of data in a window is equal to a value), or any other appropriate method of determining a boundary. Reconstruction of a data block, data stream, file, or directory includes using references to the one or more segments that originally made up the data block, data stream, file, or directory. Segments such as **202**, **204**, and **206** are stored in storage device **210**' for example, as stored segments **212**, **214**, and **216** respectively.

FIG. **3** is a block diagram illustrating an embodiment of file references. In some embodiments, file references can be used to reconstruct a file from segments stored in a storage device such as storage device **210**. In the example shown, file **300** can be reconstructed using segment references **302**, **304**, **306**, and **308**. File **310** can be reconstructed using segment references **312**, **314**, **316**, and **318**. Offsets are stored to enable the reconstruction of files using segment references in the case that there is an overlap or only a portion of the segment reference is used in the reconstruction of the file. A similar referencing structure can be used for a data block, a data stream, a directory, or any other unit of data to enable their reconstruction using segments stored. In various embodiments, a segment reference comprises a content-based reference, a non-content-based reference, a fingerprint, or any other appropriate reference for a segment.

FIG. **4**A is a block diagram illustrating an embodiment of a data structure. In some embodiments, the data structure of FIG. **4** is used to indicate if a segment was referenced to determine if the segment should be replicated. In the example shown, the data structure **400** includes a plurality of bit locations represented by **401**, **402**, **404**, **406**, **408**, and **410**. The bit locations are initialized to '0'. For a segment that is referenced, a plurality of hashes of the segment reference are calculated—for example, in FIG. **4**A hashes of the segment reference are represented by Hash(Seg Ref) **412**, **414**, **416**, and **418**. The value of the hash is used to point to a bit location in data structure **400**. The bit location pointed to is turned to a '1'. To check if a segment is indicated for replication, the same hashes of a reference to the segment are computed and if all the bits in the locations pointed to by the hashes have been set to a '1', then the segment is presumed to be referenced and should therefore be replicated. In some cases, a segment may appear to be referenced because all bit locations have been set to a '**1**' even though a reference to the segment was not indicated. Such collisions occur when a combination of other segments indicated happen to set all the locations to a '1'. The length of data structure and the number of hash functions is selected to balance the space required for the data structure, the computation required for the hash functions, and the number of tolerable collisions in the data structure for the segments. It is desirable that data structure **400** be able to indicate reasonably accurately whether a given segment has been referenced so that few segments that do not need to be replicated are replicated. In various embodiments, data structure **400** comprises a Bloom filter or a similar data structure based on hashes.

FIG. **4**B is a block diagram illustrating an embodiment of a data structure. In the example shown, data structure **420** can be used to determine a list of inexact references to segments.

A plurality of shortened references is represented in FIG. **4**B by **422** and **424**. Shortened reference **422** is created from segment reference **430** and placed in data structure **420**. Shortened reference **424** is created from segment reference **432** and placed in data structure **420**. For example, a shortened fingerprint such as n-bytes (e.g., 4) of a m-byte (e.g., 24) segment reference can be used as an inexact reference where n is less than m. Segments with references that match in the n-bytes of any of the shortened fingerprints of the data structure are added to a list of segments that are to be sent over from an originator system to a replica system. The use of the n-byte match ensures that necessary segments are replicated. There may be some additional segments transferred. On the other hand, memory space is reduced in using a shortened (e.g., a 4-byte) comparison as opposed to a full (e.g., 24-byte) comparison.

FIG. **4**C is a block diagram illustrating an embodiment of a data structure. In the example shown, data structure **440** can be used to determine a list of exact references to segments. A plurality of references is represented in FIG. **4**C by **442** and **444**. Reference **442** is created from segment reference **450** and placed in data structure **440**. Reference **444** is created from segment reference **452** and placed in data structure **440**. The data structure of exact segments referenced can be used in the process of seeding replication in a replica.

FIG. **5** is a flow diagram illustrating an embodiment of a process for seeding replication. In some embodiments, the process of FIG. **5** is used to seed a replica system such as replica system **120** of FIG. **1**. In some embodiments, the process of FIG. **5** is used to copy a set of data from one system to another. In the example shown, in **500** file(s) is/are selected to be replicated. In various embodiments, file(s) is/are selected using selection of one or more files in a graphic user interface, using a list of files, by clicking in a window, by selecting a directory, by selecting a plurality of directories, using a list of directories, or any other appropriate method of selecting files. In various embodiments, the file(s) may be determined automatically by the system for the purpose of load balancing, meeting quality of service targets or other reasons. In various embodiments, the files to be transferred may implement logical block devices, virtual tape cartridges, or other kinds of sets of data or portions of such sets of data. In **502**, file metadata and segment references for selected files are replicated and segment references are added to a data structure used to indicate that at least determined segments are to be replicated. In some embodiments, more segments than those necessary for reconstruction of the selected file(s) are indicated to be replicated. In **506**, a first candidate segment stored on a deduplicating system is selected. In **508**, it is determined if the data structure indicates that the selected candidate segment is to be replicated. If the selected candidate segment is to be replicated, then in **510** the selected candidate segment is replicated and control passes to **512**. If not, control passes to **512**. In **512**, it is determined if there are more candidate segments. If so, then in **514** the next candidate segment is selected and control passes to **508**. In some embodiments, when possible the next candidate segment selected in **514** is one stored (e.g., on the deduplicating storage system) in close proximity to the previous segment for efficient access. If there are no more segments in **512**, then the process ends. In some embodiments, every segment stored in the deduplicating storage system is a candidate for replication. In some embodiments, the candidate segments are processed substantially in the order they are located in the deduplicating storage system. This can provide efficiencies by reducing the time spent accessing the segments (e.g., accessing segments in batches or not requiring substantial seeks before a next segment access).

FIG. **6** is a flow diagram illustrating an embodiment of a process for determining referenced segments. In some embodiments, the process of FIG. **6** is used to implement **502** of FIG. **5**. In the example shown, in **600** a first file is selected. In **601**, the selected file's metadata (e.g., file name, file size, file create date, etc.) is replicated. In **602**, a first reference of the selected file is selected. In **604**, the reference is replicated. In **606**, segment reference is added to a data structure used to indicate that at least determined segments are to be replicated. In **608**, it is determined if there are more references. If so, then in **610** a next reference is selected and control passes to **604**. If not, then in **612** it is determined if there are any more files. If so, then in **614** a next file is selected and control passes to **602**. If not, the process ends.

FIG. **7**A is a flow diagram illustrating an embodiment of a process for adding to a data structure. In some embodiments, the process of FIG. **7**A is used to implement **606** of FIG. **6**. In the example shown, in **700** it is determined if the segment referred to by the selected reference is already in an exact list. If so, then the process ends. If not, then in **702** the segment is added to the exact list. The exact list comprises a list of unambiguous references to segments. For example, a list of segment fingerprints or other kinds of references. In various embodiments, the list is generated in such a way as to eliminate or not eliminate duplicate segments appearing on the list, and/or at a time when storing the original files on the originator storage system or at a later time as needed. In some embodiments, the list is sorted by segment reference. In some embodiments, the list is sorted by storage location.

FIG. **7**B is a flow diagram illustrating an embodiment of a process for adding to a data structure. In some embodiments, the process of FIG. **7**B is used to implement **606** of FIG. **6**. In the example shown, in **710** a plurality of hashes is computed of the selected reference. In **712**, each of the plurality of hashes is used to change the data structure, if appropriate. If the location has already been changed (e.g., set to '1'), then the location is not changed. In some embodiments, the hash value is used to determine a bit location in the data structure to set to a '1' value. The data structure can be used to determine if a segment was referenced.

FIG. **7**C is a flow diagram illustrating an embodiment of a process for adding to a data structure. In some embodiments, the process of FIG. **7**C is used to implement **606** of FIG. **6**. In the example shown, in **720** a shortened reference is created. In **722**, the shortened reference is added to the data structure. In some embodiments, the data structure is a long list of shortened references. The data structure can be used to determine if a segment was likely referenced.

In some embodiments, the data structure comprises the list of segments to be replicated as generated by the process of FIG. **6**.

FIG. **8**A is a flow diagram illustrating an embodiment of a process for replicating a segment. In some embodiments, the process of FIG. **8**A is used to implement **510** of FIG. **5**. In the example shown, in **800** a segment is sent to the replica system. In this example, the operating assumptions are that the replica system does not already have a copy of the segment and that the segment successfully reaches the replica system. In some embodiments, an acknowledgement is received indicating that the segment has been received and/or stored on the replica system (not shown).

FIG. **8**B is a flow diagram illustrating an embodiment of a process for replicating a segment. In some embodiments, the process of FIG. **8**B is used to implement **510** of FIG. **5**. In the example shown, in **810** a segment identifier is sent to the replica system. In **812**, an indication is received if the segment is stored on the replica system. In **814**, it is determined if the indication indicates that the segment is stored on the replica system. If so, then the process ends. If not, then in **816** the segment is sent to the replica system. In some embodiments, an acknowledgement is received indicating that the segment has been received and/or stored on the replica system (not shown).

Although the foregoing embodiments have been described in some detail for purposes of clarity of understanding, the invention is not limited to the details provided. There are many alternative ways of implementing the invention. The disclosed embodiments are illustrative and not restrictive.

What is claimed is:

1. A system for seeding replication, comprising:

a hardware processor configured to:

select one or more but not all files stored on an originating storage system to be replicated on a replica storage system;

determine one or more segment references comprising the one or more selected files;

create, at the originating storage system, a data structure that is used to indicate one or more segments to be replicated, by adding the determined one or more segment references to the data structure, wherein

the data structure is a Bloom filter which comprises a list of shortened segment references created by taking n bytes of at least one m-byte segment reference of the one or more segment references, wherein n is less than m, and

the data structure is created without communication with the replica storage system; and

determine that a candidate segment stored on the originating storage system is to be replicated based on the data structure; and

a memory coupled to the processor and configured to provide the processor with instructions.

2. The system as recited in claim **1**, wherein the data structure indicates that the candidate segment corresponds to at least one of the one or more segments references comprising the one or more selected files.

3. The system as recited in claim **1**, wherein the originating storage system comprises a deduplicated storage system.

4. The system as recited in claim **1**, wherein the replica storage system comprises a deduplicated storage system.

5. The system as recited in claim **1**, wherein the processor is further configured to:

in the event the candidate segment is determined to be replicated, send a segment identifier associated with the candidate segment to the replica storage system; and

receive an indication from the replica storage system indicating whether the candidate segment is already stored on the replica storage system.

6. The system as recited in claim **5**, wherein the processor is configured to replicate the candidate segment on the replica storage system only in the event that the indication from the replica storage system indicates that the candidate segment is not already stored on the replica storage system.

7. The system as recited in claim **1**, wherein the list of shortened segment references is created based at least in part on one or more hashes of the one or more segment references.

8. The system as recited in claim **1**, wherein the processor is further configured to:

in the event that the candidate segment is determined to be replicated, replicate the candidate segment to the replica storage system.

9. The system as recited in claim **1**, wherein the one or more referenced segments are added to the data structure at least in part by replicating the one or more segment references.

10. The system as recited in claim **1**, wherein at least some unique segments stored on the originating system are referenced by and used to reconstruct more than one of the selected files.

11. A method utilizing at least one hardware processor for seeding replication comprising:

selecting one or more but not all files stored on an originating storage system to be replicated on a replica storage system;

determining, using the processor, one or more segment references comprising the one or more selected files;

creating, at the originating storage system, a data structure that is used to indicate one or more segments, to be replicated, by adding the one or more segment references to the data structure, wherein

the data structure is a Bloom filter which comprises a list of shortened segment references created by taking n bytes of at least one m-byte segment reference of the one or more segment references, wherein n is less than m, and

the data structure is created without communication with the replica storage system; and

determining that a storage candidate segment stored on the originating system is to be replicated based at least in part on the data structure.

12. A computer program product for seeding replication, the computer program product being embodied in a non-transitory computer readable storage medium and comprising computer instructions for:

selecting one or more but not all files stored on an originating storage system to be replicated on a replica storage system;

determining one or more segment references comprising the one or more selected files;

creating, at the originating storage system, a data structure that is used to indicate one or more segments to be replicated by adding the one or more segment references to the data structure, wherein

the data structure is a Bloom filter which comprises a list of shortened segment references created by taking n bytes of at least one m-byte segment reference of the one or more segment references, wherein n is less than m, and

the data structure is created without communication with the replica storage system; and

determining that a storage candidate segment stored on the originating system is to be replicated based at least in part on the data structure.

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